On the Markov Modeling of Digital Communication Channels

(Invited Paper)

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Abstract—Evaluation, testing, and performance analysis of modulation, coding, multiple access, diversity methods and other countermeasure techniques over stochastic communication channels requires as accurate channel model as possible leading to immense complexity of such models. However, even have a very accurate method the “perfect simulation” of the channel would remain impossible because of the nonstationary stochastic behavior of most of the communication channels, especially the wireless ones. Fortunately, for different techniques different level of abstraction of the reality can be taken into account without any/or significant influence on the performance analysis of such techniques. This paper deals with Markov models applicable for stochastic simulation of the digital communication channels. Different level of abstraction to deduce digital processes from the analog channel measured and the relevant error gap and burst characteristics necessary to evaluate the appropriate Markov model will be introduced by some examples. Special attention is paid for the renewalness properties of the gap and burst processes. One of the main finding of this paper is the statement, that to carried out the appropriate choice of the Markov model the renewalness properties of both burst and gap processes should be taken into account simultaneously. In addition, according to the best knowledge of the author, the duality relation between the gap and burst processes is first time introduced. Section IV propose ak efficient simulation of the channel.

Index Terms—wireless channel, Markov chain, stochastic processes, error burst and gap processes, renewal property, duality, multipath fading, fade and interfade duration

I. INTRODUCTION

The radio channels of mobile, personal, terrestrial or satellite, high altitude platform or other kind of communications are highly influenced by fading phenomena caused by different wave propagation effects during transmission at the applied frequencies e.g. in [1]. Because of such stochastic behavior of the wireless channels deterministic characterization or realistic stochastic emulation in all aspects are close to impossible. Fortunately, by evaluation of the necessary techniques including modulation, coding, multiple access schemes, diversity systems, MIMO applications, and other fade countermeasure methods to achieve the required signal quality of the provided services the exact knowledge of the causes of the received signal degradation is not needed. Appropriate models able to characterize the wireless channels in the aspect of interest could provide the right engineering environment for evolution of successful techniques with respect to the channel behavior addressed e.g. in [2]. The goal of this paper is to present a method for the right choice of the appropriate Markov model. The first step is the determination of the renewalness properties of the error gap and burst processes of the time discrete binary stochastic process deduced from a realization of the wireless channel considering the abstraction of interest. A large class of Markov models is introduced classifying the models according renewalness of their generated gap and burst processes. Choosing the Markov model with the same renewalness properties as the channel of interest has promises of efficient simulation of the channel.

Note, that all the given relations, proofs and statements in this paper are valid for stationary digital processes. Even the real wireless channel almost shows non stationary there is often possible to segment the process to stationary intervals. In many cases the transition process between stationary periods of the non stationary channel can be regarded as stationary. This is the case for example in cyclostationary channels. Therefore, a coupled set of Markov chain models can overcome of this non stationary phenomenon applying one Markov model for the switching process to control the other models developed for the stationary periods.

The paper is organized as follows; Section II describes the principle of transformation of the analog channel to a digital process and the equivalent representations of the digital channel with the error, gap and burst processes are given. In Section III the statistical properties of these processes are investigated and the duality between the gap and burst processes are first time introduced. Sections IV propose a large class of Markov models and give the model classifications according to the renewal properties of the generated digital processes. In Sections V and VI the investigated wireless links and the derived statistics from the digital processes both of measured channel and Markov models are compared.

II. REPRESENTATION OF DIGITAL CHANNELS

This paper deals with the appropriate choice of discrete time, discrete state homogeneous first order Markov chain models able to characterize the stochastic properties of the digital channel derived from measured wireless channel with respect of the digital properties of interest. For this purpose the measured analog time function of the received power of the wireless channel has been sampled and digitalized by an A/D converter. The recorded data are then used to produce the binary bit or symbol error sequence, according to the applied modulation. A digital fading process is then defined being 1 if
the attenuation is higher than the given threshold and 0 if it is lower than the threshold. Other kind of digital stochastic processes are introduced in the following sections.

Let $E = \{e_i \mid i \in I, e_i = 0,1\}$ denote the time discrete binary stochastic process deduced from a realization of the wireless channel considering the abstraction of interest. According to the level of abstraction a particular event $e_i$ denote the binary random value of the $j$th event e.g. the correctness of a received bit or symbol (i.e. $e_i=0$ if the bit received without error and $e_i=1$ for corrupted bit), interfering/fading periods, the channel state information (good/bad), the LOS/NLOS information or other qualities. Without loss of generality let call the process $E$ as error process, the event $e_i = 0$ non-error and $e_i = 1$ an error. Let also define the a priori probability $p = \Pr\{e_i = 1\}$ called as error probability in the following.

In addition to the process $E$ let us further define two stochastic descriptions of the same process. Let $G = \{g_i \mid i \in I\}$ denote the gap process and $B = \{b_k \mid k \in I\}$ denote the burst process with the meaning of e.g. error gap, “good”, interference, LOS process and of e.g. error burst, “bad”, fade, NLOS process, or similar abstraction respectively. Fig. 1 shows the relation between the processes $E$, $G$, and $B$ respectively.

A. Mass Functions and Renewal of the Gap and Burst Processes

In this section the higher order statistics of the gap and burst processes will be investigated. This will lead up to analytical expressions to characterize the renewal properties of these processes. A gap process $G$ is called renewal, for which gap events are independently and identically distributed (iid). This is the case for the $G$ process of the memoryless binary symmetric channel (BSC), which is uniquely defined by the error probability $p$. Similarly, a burst process $B$ is called renewal if the assumption of iid. of bursts holds, e.g. for BSC.

However, for channels with memory the dependency of successive gaps and bursts should be investigated. For this purpose let us define the probability mass function (PMF) of multigap length as $M_d(m,n) = \Pr\{g^m = n\}$, the probability of a multigap of order $m$ have a length equal to $n$. In the same way the PMF of multiburst is defined as $M_b(m,n) = \Pr\{b^m = n\}$, the probability of a multiburst of order $m$ have a length equal to $n$. For BSC the PMFs of the multigap and multiburst length have a negative binomial distribution each from which the variances of the renewal $G$ and $B$ processes of BSC can be expressed as follows:

\[ \text{var}(g_{\text{BSC}}) = (1-p)\frac{p}{p^2}, \text{ and var}(b_{\text{BSC}}) = pr/(1-p^2). \]  

The renewalal properties of the gap and burst processes of the digital channel of interest can be well expressed performing the comparison between the variance of the BSC and the variance of the investigated channel. To this purpose Adoul introduced the so called variation coefficient for the multigap as follows:

\[ K_g(r) = \frac{\text{var}(g^r)}{\text{var}(g^r)}. \]  

Let us also define the variation coefficient of the multiburst length in similar way:

\[ K_b(r) = \frac{\text{var}(b^r)}{\text{var}(b^r)}. \]  

The higher order values of $K(r)$ are indicating the renewal property of the process. If $K(r) = K(1)$ for any $r$, the process is renewal; contrarily, if the variation coefficient shows a change, the statistics of the processes $E$, $G$ and $B$ could characterize the channel similarly.

III. STATISTICS OF DIGITAL CHANNELS

To achieve a deep insight in the error structures of the time discrete binary error process $E$ the probability that $m$ errors occurs within a block of $n$ consecutive events $P(m,n)$ called block error density function is a very important statistic. Clearly, for comprehensive description of any stationary process $E$ the joint knowledge of $P(m,n)$ for all positive $n$ and $0 \leq m \leq n$ would be necessary. For digital channel with renewal gap process $G$ Elliott [4], for nonrenewal finite state channel [5] gives a recurrence relation to calculate $P(m,n)$ functions. However, for general digital channels, especially for channels with memory it would be complicated to obtain such ensembles of $P(m,n)$ functions. Instead of this let us find the relations between $P(m,n)$ function of the error process $E$ and the statistics easily obtainable from the gap and burst processes $G$ and $B$, respectively.

Figure 1. An example of error process $E$, gap process $G$, and burst process $B$. 

An arbitrary gap event of $G$ begins immediately after an error event and close with the first occurrence of the next error (included) of $E$ following the definition given by Adoul [3]. Let us define the length of a gap event as the number of the binary random variables of the $E$ process included in this gap event. For example the gap event with the arbitrary index $i$ including the binary events $e_{i-1}$, $e_i=0$, $e_{i+1}$ has the length $g_i=3$ as depicted in Fig. 1. Similarly to Adoul definition for gap event let us define an arbitrary burst event of the burst process $B$ between two successive non-error events of the error process $E$ e.g. the burst event with an arbitrary index $k$ including the binary events $e_{i-1}$, $e_{i+1}$, $e_i=0$ and $e_{i+1}$ has the length $b_i=4$ as also depicted in Fig. 1. To be able to determine the statistical dependency between successive gap and burst events let us define the multigap of order $r$ consisting of $r$ consecutive gap events beginning with a gap with an arbitrary index $j$, having the length $g^r=g_j\cdots g_{j+r-1}$ and the multiburst of order $r$ consisting of $r$ consecutive burst events beginning with a burst with an arbitrary index $k$, having the length $b^r=b_k\cdots b_{k+r-1}$.

Note that both processes $G$ and $B$ are equivalent descriptions of the process $E$, because from both of the gap and burst event length sequences $\{g\}$ and $\{b\}$ the error process $\{e\}$ can be reconstructed. Therefore from the point of view of stochastic behavior of the abstracted binary channel of interest, the statistics of the processes $E$, $G$ and $B$ could characterize the channel similarly.
it is nonrenewal. Furthermore, the further is $K(1)$ from one, the less true is the assumption that the channel is memoryless; if $K(1)$ is greater than one, the process is more variable, the lengths of the gap and burst events are spread from their mean value and the error events are appearing in bursts. The correlation between the successive events shows the tendency of the event length variation. A positive correlation, i.e. the variation coefficient increases with the order, indicates that a short event will be followed by a short one and a long event with a long one. The negative correlation indicates that a short event will be followed by a long one and vice versa.

B. Relations between gap, burst and error density

For BSC the error density $P(m,n)$ can be easily calculated according the binomial distribution as:

$$P(m,n) = \binom{n}{m} p^m (1-p)^{n-m}. \quad (4)$$

For more general channels, regardless of the renewal property of $G$ Adoul [3] gives the duality relation between $P(m,n)$ and the PMF of multigap length $M_{\Delta}(m,n)$:

$$\Delta^\Delta P(m,n) = p \Delta^\Delta M_G(m,n), \quad (5)$$

valid for $3 \leq m \leq n$, where $\Delta^r$ notes the $r$th order discrete derivate of a function $A(i)$ with respect to index $i$ according the following definition

$$\Delta^r A(i,j) = \Delta^{r-1} A(i,j) - \Delta^{r-1} A(i-1,j) \quad for \quad r = 1, 2, 3 \ldots$$

for any positive $k$.

Unfortunately, this duality relation between the error density and the multigap length distribution does not cover the very important cases $P(0,n)$ and $P(1,n)$ having a block of $n$ events without error and contain only one error. Therefore, let introduce the new duality relation linking the error density with the PMF of the multiburst length:

$$\Delta^\Delta P(n-m,n) = (1-p)\Delta^\Delta M_B(m,n), \quad (7)$$

valid for $3 \leq m \leq n$. The proof of this duality can be carried out in similar way as given for eq. (5) in appendix of [3].

Now, applying both duality relations simultaneously, $P(m,n)$ can be determined for any positive $n$ and $0 \leq m \leq n$ from the PMFs of the multigap and multiburst length $M_G(m,n)$ and $M_B(m,n)$, respectively, providing the perfect instruments in all statistical aspects.

As new results let us also introduce the duality relations first time published between the PMF of multigap and multiburst length, without any proof because of lack of place:

$$p \Delta^\Delta M_G(m,n) = (1-p)\Delta^\Delta M_B(n-m,n), \quad (8)$$

and

$$p \Delta^\Delta M_G(n-m,n) = (1-p)\Delta^\Delta M_B(m,n), \quad (9)$$

both relations are valid for $3 \leq m \leq n$. Unfortunately, according to the definition in Fig. 1 the relations between the multigap and multiburst lengths equal to the order can not be expressed neither by (8) nor by (9), which also imply to the joint investigation of the multigap and multiburst processes.

Furthermore, two real channels can show similar nonrenewal properties of the gap processes but different renewal properties renewal/nonrenewal of the burst processes, or vica versa. These statements justify the equal importance to take both multigap and multiburst statistics into account by evaluation of an appropriate Markov model for the digital channel of interest.

IV. CONSIDERING APPROPRIATE MARKOV MODEL

To reproduce the correct channel properties a suitable digital model has to be selected with similar renewal properties. Let us concentrate on the discrete time, discrete state homogenous first order Markov chain models. One of the most general models of this type was published by Fritchman [6] with finite number of states to characterize the error structure of binary communication channels. Recall, that in this paper the expressions error and error free are used in a more general way meaning the two possible binary event of the time discrete binary stochastic process deduced from a realization of the wireless channel considering the abstraction of interest as described in Sections II.

A. The Fritchman model

The Fritchman model is a partitioned $N$-state Markov-chain with $k$ error-free states in state partition $G$ and $N-k$ error states in the state partition $B$ as shown in Fig. 5 with the state transitions probabilities $P_{ji}$.

![Fritchman's N-state partitioned Markov model](image)

According to the partitioning the state transition probability matrix $P$ which totally determines this model can be expressed as follows:

$$P = \begin{pmatrix} P_{GG} & P_{GB} \\ P_{BG} & P_{BB} \end{pmatrix}. \quad (10)$$

Deriving the right parameters of $P$ form the digital error process $E$ is very troublesome. In the special case of the Fritchman model that no transition between the states of the same partition are allowed, in other words $P_{GG}$ and $P_{BB}$ are diagonal matrices the complementary cumulative distributions $F^C$ of the partition durations which are in close relation with the PMF of multigap and multiburst processes produced by the model can be expressed in a simple way for both error free partition $G$ and error partition $B$:

$$1 - \sum_{i=1}^{n} M_G(i,i) = F^C_G(n) = \sum_{i=1}^{k} \left( \sum_{j=k+1}^{N} \frac{Z_j P_{ji}}{Z_B} \right) P_{ii}^n, \quad (11)$$
and

\[ 1 - \sum_{i=1}^{V} M_B(1,i) = E^C_B(n) = \sum_{i=1}^{V} \left( \sum_{j=1}^{N} \frac{Z_j}{P_{ji}} \right) P_{ii}^n, \]  

(12)

where \( Z_j \) and \( Z_{ij} \) are steady state probabilities of the state \( j \), partition \( G \), and partition \( B \), respectively. The equations above could provide some initial values for parameter optimisation of the transition matrix \( P \) to achieve realistic model for the given digital error process. Applying further model simplification that is using only one state in one of the partition the parameterisation of the model becomes easier for example using the method given in [7].

According to the structure of the Fritchman model the generated error processes can show both type of renewaless the renewal and the nonrenewal properties of both processes gap and burst respectively. Table 1 classifies the Fritchman model with respect to the renewaless of the generated burst and gap processes [8].

**Table 1. Classification of the Fritchman model**

<table>
<thead>
<tr>
<th>Number of states in partition</th>
<th>Generated processes</th>
<th>Analogy to other models:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Renewal (R)</td>
<td>Gilbert [9], Swoboda [10], Gilbert-Elliott [4], McCullough [11], Cygan [12]</td>
</tr>
<tr>
<td></td>
<td>Nonrenewal (NR)</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>k=1</td>
<td>N-k=1</td>
<td>R</td>
</tr>
<tr>
<td>k=2</td>
<td>N-k=1</td>
<td>R</td>
</tr>
<tr>
<td>k=1</td>
<td>N-k&gt;1</td>
<td>R</td>
</tr>
<tr>
<td>k&gt;1</td>
<td>N-k=1</td>
<td>NR</td>
</tr>
<tr>
<td>k=2</td>
<td>N-k=2</td>
<td>NR</td>
</tr>
<tr>
<td>k=4</td>
<td>N-k=4</td>
<td>NR</td>
</tr>
<tr>
<td>k&gt;1</td>
<td>N-k=1</td>
<td>NR</td>
</tr>
</tbody>
</table>

There are a number of different types of digital Markov models given in the literature for characterisation of the time discrete binary stochastic channels. Fortunately, for several digital models the transformation to the Fritchman model is possible as also given in Table 1. Because of great importance and frequent applications let us here only introduce the Gilbert-Elliott model.

**B. The Gilbert-Elliott Model**

The Gilbert-Elliott model [4] is a two state Markov chain. One of the states, denoted by \( G \), represents the “good” channel with nonzero error probability \( e_G \) much less than the error probability \( e_B \) of the other state \( B \), represent the “bad” channel as depicted in Fig. 3.

![Figure 3. The Gilbert-Elliott model](image)

The model parameters of the Gilbert-Elliott model can not be unambiguously determined from the statistics of the measured process [13]. Iterative optimization of the Gilbert-Elliott model parameters can be applied to be able to simulate the measured multiple gap and burst statistics with the least error. For the parameter optimization the Kolmogorov-Smirnov test [14] has been applied. The test compares the distribution of the measured events with a hypothetical distribution and takes a confidence level to accept or reject the hypothetical distribution as an approximation of the original distribution. With this method the optimized transition matrix of the Gilbert-Elliott model and the \( e_G \) and \( e_B \) probabilities can be calculated. The model can be transformed to a 4 state Fritchman model with 2 error free and 2 error states.

Once determined the renewaless properties of the gap and burst processes of the time discrete binary stochastic process deduced from a realization of the wireless channel considering the abstraction of interest the type of the appropriate Markov model able to generate the binary stochastic process with the required renewal/nonrenewal gap and burst properties can be selected from Table 1.

**V. The Investigated Wireless Links and the Abstracted Digital Channels**

For demonstration purpose two different types of wireless channel and two kinds of digital abstraction of the measured channels will be introduced in the following.

**A. Parameters of the measured wireless links**

In Table 2 the parameters of the investigated wireless channels are given. The first type of the data gathered in measurement campaign performed during 1984-87 [15]. Channel A is the measurement data of a land mobile satellite channel received on board of a moving vehicle with a speed of 10 km/h in a highly built-up city area. The observable channel impairments like multipath fading and shadowing are producing even 30-40 dB decrease of the received power.

The second type of the data form measurements of a high frequency terrestrial radio link in Hungary, Channel B is a point-to-point millimetre wave feeder link of a cellular mobile system.

**Table 2. Description of the measured wireless channels**

<table>
<thead>
<tr>
<th>Channel A: The land mobile satellite link</th>
<th>Channel B: The terrestrial point-to-point feeder link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite</td>
<td>Link name</td>
</tr>
<tr>
<td>MARECS (d=39150 km, geostat.)</td>
<td>HU11</td>
</tr>
<tr>
<td>Elevation</td>
<td>Location</td>
</tr>
<tr>
<td>24°</td>
<td>Budapest</td>
</tr>
<tr>
<td>Frequency</td>
<td>Frequency</td>
</tr>
<tr>
<td>1.54 GHz</td>
<td>38 GHz</td>
</tr>
<tr>
<td>Sampling rate</td>
<td>Polarization</td>
</tr>
<tr>
<td>300.5 Hz</td>
<td>Horizontally</td>
</tr>
<tr>
<td>Vehicle speed</td>
<td>Path length</td>
</tr>
<tr>
<td>10 km/h (city)</td>
<td>1.5 km</td>
</tr>
<tr>
<td>Measurement duration</td>
<td>Sampling rate</td>
</tr>
<tr>
<td>27.8 min</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Measurement duration</td>
<td>Measurement duration</td>
</tr>
<tr>
<td>June, 2004</td>
<td>May, 2004</td>
</tr>
</tbody>
</table>
A data collecting system samples with 1 Hz sampling rate the received power of the radio links and continuously stores their digitalized values. The observable channel impairments are caused by different types of precipitation, mainly the rain, which can produce even 40 dB decrease of the received power during the heavy rain periods. To smooth the digitalized signal and decrease the influence of scintillation a 4 sec moving average filter has been applied. Both channel records are normalised having 0 dBm the mean value of the received power process $p(t)$.

**B. The Abstracted Digital Channels**

In this section two different types of digital abstractions from the measured wireless channels will be introduced.

The first type is the symbol error process (SEP) derived from the land mobile channel recorded data by applying coherent QPSK modulation and assuming 10 dB $E_{L_{tot}}/N_0$ signal to noise ratio (SNR) without fading. The recorded power process is read sample by sample by software and with the symbol error probability of the QPSK modulation at the instantaneous SNR

$$P_{QPSK}(\frac{p(t)}{\sqrt{2}N_0}) = \text{erfc}\left(\sqrt{\frac{\rho(t)E_{tot}}{2N_0}}\right) - \frac{1}{2}\left(\text{erfc}\left(\sqrt{\frac{\rho(t)E_{tot}}{2N_0}}\right)\right)^2$$ (13)

the random binary SEP is generated symbol by symbol.

The second type of the abstracted digital process from the measurements is the digital fading process (DFP). Let us define the fade duration as the time interval between two crossings at the same attenuation threshold, where the attenuation is higher than the threshold. Similarly, the interfade duration is defined as the time interval where the attenuation is below the same threshold [16]. According to this definition, fade events marked e.g. with the binary value 1 (corresponding to the “error” event) occurs within the fade duration and interfade events marked with 0 occurs within the interfade duration. To generate the DFP form the measured channels the recorded power process was read sample by sample by software and the binary 0 or 1 was the output when the instantaneous power was above or below the given fade threshold, respectively.

Because of very frequent occurrences of symbol errors the derived process will not be shown. In Fig. 4 and 5 a segment of the received power process of channel A and B and the corresponding DFP are depicted for 10 dB and 5 dB threshold, respectively.

**VI. CHOOSING THE APPROPRIATE MODEL BASED ON GAP AND BURST RENEWALNESS**

Having derived the digital processes SEP and the two DFP from the wireless channel the next step in the model evaluation is to determine the renewal properties of the gap and burst processes $G$ and $B$ for each binary channels respectively. According to statements in section III the variation coefficients given in equations (2) and (3) can be used as tests of renewal for both $G$ and $B$ processes. In Fig. 6 to 8 the $K_G(r)$ and $K_B(r)$ of the derived binary channel normalised to its first order variation coefficients marked with “Measured $K_G(r)/K_G(1)$” and “Measured $K_B(r)/K_B(1)$” are depicted for each derived binary channels SEP, DFP with 10 dB and DFP with 5 dB thresholds, respectively.

In the case of the SEP both gap and burst processes show nonrenewal property. According to the statements in section IV the appropriate Markov model can be selected from Table 1. From the 4 model expressing nonrenewal burst and gap processes we choose the simplest one, the Gilbert-Elliott model. Next step is the parameterisation of the selected model using e.g. the method given in subsection B of section IV. Fig. 6 also gives the normalised variation coefficients marked with “Modeled $K_G(r)/K_G(1)$” and “Modeled $K_B(r)/K_B(1)$” determined from the binary SEP produced by the Gilbert-Elliott model with the given parameters. Comparing the measured and modeled results good agreement can be stated.

Both processes $G$ and $B$ are positively correlated, however the $B$ process shows higher variability. All this aspects are reproduced by the selected Gilbert-Elliott model.

In the case of DFP derived from channel A and B the gap process shows renewal and the burst process nonrenewal property as shown in Fig. 7 and 8. The higher values of the $K_B(r)$ of DFP on channel A indicates more variability in the burst process compared to the DFP on channel B as also obtainable comparing Fig. 4 with 5. For modelling purpose a 5-state-Fritschman model with one error free state and diagonal $P_{BB}$ is selected from Table 1 producing renewal $G$ and nonrenewal $B$. The parameterisation of the selected type of model can be realised using e.g. the method given in subsection A of section IV. For both DFP channel A and B the determined parameters of the $P$ matrices are shown in Fig. 7 and 8 respectively. The selected Fritschman models are

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**Figure 5.** Channel B, received power and the corresponding DFP at 5 dB threshold.
showing the renewal property of the $G$ perfectly, however the
variability of the nonrenewable $B$ process of the measured
channel are somewhat underestimated for both cases channel
A and B. The reason for that can be the imperfect estimation
of the transition probability matrices.

\begin{align*}
& \text{Figure 6. Normalised variation-coefficients of the multigap of order } r \\
& \text{and multiburst of order } r \text{ generated process for Channel A.}
\end{align*}

\begin{align*}
& \text{Figure 7. Normalised variation-coefficients of the multigap of order } r \\
& \text{and multiburst of order } r \text{ generated process for Channel A applying } 10 \text{ dB threshold.}
\end{align*}

\begin{align*}
& \text{Figure 8. Normalised variation-coefficients of the multigap of order } r \\
& \text{and multiburst of order } r \text{ generated process for Channel B applying } 5 \text{ dB threshold.}
\end{align*}

VII. CONCLUSIONS

The aim of this contribution was to present a useful method
for the appropriate choice of Markov model for the digital
channel of interest. The first step of the proposed method is
the determination of the renewal properties of the error gap
and burst processes of the time discrete binary stochastic
process deduced from a realization of the wireless channel
considering the abstraction of interest. A large class of Markov
models was also introduced classifying the models according
renewal properties of their generated gap and burst processes.
Choosing the Markov model with the same renewal properties
of both gap and burst processes jointly as the channel of interest
has promises efficient simulation of the channel. First time published,
this contribution introduces the duality relations between the probability mass functions
of multigap and multiburst length of binary sequences. Applying
both duality relations simultaneously, the error density function $P(m,n)$
can be determined for any positive $n$ and $0 \leq m \leq n$ from the probability mass functions of the multigap
and multiburst length, providing the perfect instruments for
characterization of binary sequences in all statistical aspects.

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